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REVIEW

An overview of the common bacterial diseases of potato in Pakistan, associated crop losses and control stratagems

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Abstract
Potato, an important food crop and a rich source of nutrients and energy, is widely cultivated under diverse climatic conditions. The crop substantially contributes to the provision of global food supply along with cereals maize, wheat, and rice. In the wave of increasing population of the world and its food requirement, increase in productivity of potato is crucially required. Being a highly adaptable crop to diverse climates, production of the crop is still limited due to different biological and non-biological constraints. Several fungal and bacterial pathogens incite severe diseases in the potato crop. Among the bacterial diseases, common scab (*Streptomyces scabiei, S. europaeiscabiei, S. acidiscabiei* etc.), soft rot and blackleg (*Pectobacterium* sp. and *Dickeya* sp.) and bacterial wilt (*Ralstonia pseudosolanacearum*) are significant constraints to production output and marketing acceptability of the crop particularly in environments which are conducive to the pathogenicity of these organisms. This review examines commonly prevailing bacterial diseases of potato, their impact on crop yield and respective control measures with a specific focus on the occurrence of such diseases in Pakistan.

Keywords Crop production · Biotic constraints · Host defense · Pesticides application · Integrated disease management

Introduction

Potato (family Solanaceae) is one of the most cultivated and consumed crops after maize, rice, and wheat; a rich source of carbohydrates, minerals and caloric energies, which serves as a staple food in many regions of the world providing food to more than 10 million peoples (Majeed et al. 2017). Currently, global potato production exceeds 376 million tonnes harvested from an area of 19.25 million hectares (FAOSTAT 2018). Although the global crop production has been substantially increased since the 1970s, increase in population and its growing food demands stresses for more elevated yields to avoid future food problems (Majeed 2017).

Potato is grown in a variety of climatic conditions preferably in tropics of Pakistan and throughout the world. Being a versatile crop and owing to a short growth period (lasting up to three months), potato cultivation and its production can be promoted significantly by employing sustainable agricultural methods. Nevertheless, several factors challenge the production and yield potentials of potato crop which ranges from increased pathogenic infections of fungal and bacterial origins to abiotic extremes such as temperature fluctuations, soil conditions and water availability (Majeed et al. 2014a, b; Majeed and Muhammad 2018). Different pathogenic bacteria parasitize the crop and result in yield losses which generally depend on climatic conditions, varieties of potato, pathogenic strains and precautionary measures. Actual crop losses may greatly vary in different geographic locations, growing seasons and in different cultivars. However, some bacterial diseases such as common scab (*Streptomyces scabiei, S. europaeiscabiei, S. acidiscabiei, S. turgidiscabiei* and other species), soft rot and blackleg (*Pseudomonas* sp., *Pectobacterium* sp. and *Dickeya* sp.) and bacterial wilt (*R. pseudosolanacearum*) are commonly prevalent in almost all regions where the potato is grown (Raza et al. 2016; Czajkowski et al. 2011; Braun et al. 2017a, b). Their effect on growth and production of the crop are considerably variable in different potato growing areas. Annual losses of the potato crop in the Netherlands as a result of soft rot and blackleg have been reported to reach to 30

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million euro (Czajkowski et al. 2012). Similarly, bacterial wilt can cause up to 90% yield losses of potato annually throughout the world which may even exceed under favorable conditions (Nion and Toyota 2015).

In Pakistan, climatic conditions favor the propagation of potato crop. It is generally grown in three seasons –spring, summer, and autumn –both in plains and hilly areas of the country. However, production of the crop in the country is challenged with many biotic and abiotic stresses which substantially reduce the attainable yields of the crops. Leading abiotic factors include salinity, soil quality, temperature stress and lack of availability of irrigation water while different viral, bacterial, fungal and nematode diseases serve as biotic constraints in most of the potato growing zones of Pakistan. This review highlights common bacterial diseases in potato fields, their impact on crop production and control strategies.

Production and prevailing diseases of potato in Pakistan

In Pakistan, the potato is cultivated on 158 k-hectares of the area which in 2014 accounted for 3.8 million tonnes of production of the crop (ASP 2015; Majeed and Muhammad 2018). The production recorded during 2014 was substantially higher in the country when it was compared to previous years. Major potato producing provinces of the country are Punjab and Khyber Pakhtunkhwa while Sindh and Balochistan are also contributing their shares in potato production but to a lesser extent. The crop is generally grown in plains of the Punjab, Sindh and Khyber Pakhtunkhwa provinces while in hilly areas of the country in three seasons (spring, summer, and autumn). Climatic conditions of the country are suitable for cultivation and production of potato; however, they are also ideal for propagation of several phytopathogenic diseases. Major viral diseases which have a considerable impact on potato health are potato virus Y (PVY), potato virus X (PVX), potato virus S (PVS), potato virus M (PVM), potato virus A (PVA), and potato leafroll virus (Abbas et al. 2012; Naveed et al. 2017; Majeed et al. 2018). The prevalence of these viruses is generally widespread in the country where potato crop is cultivated. Among bacterial diseases, blackleg and soft rot, bacterial wilt, and common scab are the most devastating biotic constraints which prevail in the potato growing zones of the country (Majeed and Muhammad 2018). Like in many other parts of the world, late blight (*Phytophthora infestans*), early blight (*Rhizoctonia solani*), fusarium wilt (*Fusarium solani*) and black scurf (*Rhizoctonia solani*) are the most common fungal diseases in Pakistan which severely affect the growth and yield of potato crop resulting in substantial economic losses (Shafique and Shafique 2012; Majeed et al. 2014b; Majeed et al. 2018). Root-knot nematodes (*Meloidogyne* sp.) are prevalent in most of the potato growing regions of the country; however, they are abundant in hilly areas and affect potato and other root bearing crops to a significant extent (Majeed et al. 2017; Tariq-Khan et al. 2017). Crop damages and associated economic losses as result of different phytopathogenic diseases of potato crop greatly vary in the country which depend on several factors ranging from soil and environmental conditions of the potato growing areas to the use of seed quality, farmers' approach and the use of agrochemicals.

Common bacterial diseases of potato

The soil rhizosphere provides a rich environment of nutrients and water to plants and harbors diverse microbial communities. The rhizospheric bacteria are among the most significant microbiota which play a prominent role in soil building, ecosystem stability and symbiotic communion. Many of the bacterial populations are crucially required for healthy growth and development of plants, there are, however, several pathogenic strains which cause diseases on their hosts. Potato is challenged by several different bacterial pathogens. Some of these bacteria have drastic effects on physiological aspects of the potato plant, blockage of vascular vessels and production of toxins which may lead to wilting of above-ground parts of plants, rot, and decay of tubers, production of lesions and streaks on tuber surface or the inner cortex, quality deterioration and overall yield losses. Prominent bacterial diseases of potato are bacterial wilt (*Ralstonia pseudosolanacearum*), soft rot/blackleg (*Pectobacterium atrosepticum, P. carotovorum* and *Dickeya* sp.), common scab (*Streptomyces* sp.), bacterial ring rot (*Clavibacter michiganensis*), pinkeye/periderm disorder syndrome (*Pseudomonas fluorescens*) and zebra chip (*Candidatus* Liberibacter solanacearum) (Table 1). However, based on their wide-spread occurrence and severe effects on the potato crop, only bacterial wilt, common scab, and soft rot and blackleg are discussed in this review.

Bacterial wilt

Bacterial wilt caused by *R. pseudosolanacearum (*previously known as *R. solanacearum)*, is one of the most serious yield-reducing diseases in tropics, subtropical and temperate regions where potato, tomato, eggplant and several other crops are cultivated (Raza et al. 2016). *Ralstonia* sp. was formerly divided into five phylotypes which were categorized on the basis of their host range and geographical distribution (Siri et al. 2011); however, Safni et al. (2014) in a recent study, suggested that the species complex be divided into three prominent species with four phylotypes: *R. solanacearum* –phylotype II, *R. pseudosolanacearum* –phylotypes I, III and *R. syzygii* –phylotype IV (Morel et al. 2018; Safni et al. 2018).

Table 1 A list of the common prevailing bacterial diseases of potato

Disease/ causal agents	Disease symptoms	Other hosts	Occurrence	Nature of pathogen	Control methods	Reference
Bacterial wilt (*Ralstonia pseudosolnacearum, R. solanacearum, R. syzygii*)	Wilting, brown rot, chlorosis, retarded growth	Tomato, pepper, tobacco, banana, eggplant and several others	Tropical, subtropical, and warm-temperate regions, worldwide	Soil-borne	Chemical, host-resistance, biocontrol	Guo et al. (2004); Nouri et al. (2009); Safni et al. (2014); Raza et al. (2016); Cho et al. (2018)
Soft rot and blackleg (*Pectobacterium atrosepticum, P. carotovorum, P. brasiliense* etc. and *Dickeya solani, D. dianthicola, Dickeya* sp.)	Blackleg on stems, black rot on tubers and stems, leaf and stem wilting, qualitative degradation of tubers	Carrots, cucumber, onion, and several angiosperms	Temperate, subtropical, worldwide	Seed-borne, soil borne, propagated through vectors and aerial means	Chemical control, disease-free seed, biocontrol agents, natural enemies	Ma et al. (2007); Czajkowski et al. (2011); Essarts et al. (2016); Wang et al. (2017); Charkowski (2018)
Common scab (*Streptomyces scabiei, S. europaeiscabiei, S. acidiscabiei, S. turgidiscabiei, S. stelliscabiei*)	Superficial or deep corky stains on tubers, lesions development on tubers, spoilage of potato, affecting quality and acceptability of tuber	Beet, carrot, radish and parsnip, turnip, sweet potato	Temperate regions, worldwide	Soil-borne, seed-borne and found on plant debris	Chemical dressing, crop rotation, amendments of soil, biological antagonism	Goyer and Beaulieu (1997); Wanner (2006); Braun et al. (2017); Leiminger et al. (2013); Wanner et al. (2014); Tomihama et al. (2016); Sarwar et al. (2018)
Bacterial ring rot (*Clavibacter michiganensis*)	Brown circular rot, wilting, rolling of leaf margins	Tomato, wild Solanaceous species	Warm and dry conditions	Seed-borne	Proper sanitation, use of disease-free tubers	Anon (2017); Bibi et al. (2018)
Pink eye/ periderm disorder syndrome (*Pseudomonas fluorescens*)	Discoloration of tuber eyes, corky blotches on tuber surface	Fruits and vegetables	Warm and wet conditions	Soil and waterborne	–	Liao et al. (1993); Nolte et al. (1993); Paulsen et al. (2005); Lulai et al. (2018)
Zebra chip (*Candidatus Liberibacter* spp. but still controversial)	Dark strips and streaks inside tuber, stunted growth, swollen nodes and chlorosis	Tomato, pepper, carrots and many other plants	–	–	–	Crosslin and Munyaneza (2009); Li et al. (2009); Liefting et al. (2009); Alfaro-Fernández et al. (2012)

R. pseudosolanacearum which contains phylotypes I and III are the most widely occurring species. The wilt causing agent is an aerobic gram-negative bacterium with no spore forming capacities, ideally propagated at temperature range 28–32 °C (Arora and Khurana 2004). Bacterial wilt may correspond to more than 90% yield losses in tomato, potato, and other host crops if kept uncontrolled. (Aslam et al. 2017). Like other potato growing countries, the prevalence of bacterial wilt is a major problem in Pakistan contributing to significant losses as well as quality deterioration of tubers. The incidence of *R. pseudosolanacearum* in the country during 2008–09 was reported to be 13.8% (Begum et al. 2012). Tahir et al. (2014) stated that incidence of bacterial wilt in the Punjab province ranged between 24 and 60%. It is estimated that yield losses of the crop may exceed 30% as a result of bacterial wilt due to ideal climatic conditions of major potato and tomato growing zones in Pakistan (Afroz et al. 2009; Tahir et al. 2014).

The pathogen has a wide host range, exceeding 200 plants and is currently listed as the 2nd most significant pathogen among the bacterial flora of crops (Popa et al. 2016). Adversities to the crop are caused when *R. pseudosolanacearum* enters through roots or wounds and making its way to xylem where excessive production of polysaccharides by the pathogen results in blockage of water-conducting vessels, wilting and eventually death of the host plant (Raza et al. 2016). In potato, complete or partial wilting of the plant may significantly reduce tuber production due to limited translocation of photosynthate from aerial parts to tubers. Tuber infection can result in brown rots while aerial plant parts may show symptoms of wilting, leaf chlorosis and stunted growth (Cho et al. 2018).

Soft rot and blackleg

Bacterial soft rot and blackleg of potato are caused by different species of pectolytic bacteria especially *Pectobacterium atrosepticum* and *P. carotovorum*, and *Dickeya* sp. which are prevalent in regions where the potato is grown and may correspond to yield losses of more than 80% (Arora and Khurana 2004; Czajkowski et al. 2011). These bacteria were previously known as *Erwinia* species but know placed in two genera: *Pectobacterium* and *Dickeya* which contain many species and subspecies (Chung et al. 2017). Almost 10 species of *Dickeya* are known to cause soft-rot and blackleg in a diverse range of hosts but on the potato crop only *D. dianthicola* and *D. solani* have been reported for soft-rot and blackleg infections while *Pectobacterium* contains 11 species of which 5 species (*P. aroidearum, P. atrosepticum, P. brasiliense, P. carotovorum,* and *P. parmentieri*) have the potentials of causing soft-rot diseases in the potato (Charkowski 2018). The pathogens parasitize a wide host range of plants, but the potato is more severely affected in temperate regions although some species are noxious in warmer regions as well (Czajkowski et al. 2011). These bacteria are typically aerobic as well as anaerobic, gram-negative, rod-shaped, flagellated and non-spore forming pathogens with the potential capacity to produce pectin-degrading enzymes (Arora and Khurana 2004). Typical symptoms of the disease include the appearance of black rot on tubers and stem, wilting of leaves and stem in field conditions while rotting of potato tubers in storage conditions depending on the prevailing environmental conditions such as temperature and humidity (Czajkowski et al. 2011). Bacterial species which cause soft rot and blackleg are often soil borne; however, in storage conditions, contamination of healthy tubers may occur from infected tubers. The pathogens can infect host crops by penetrating into wounds, natural openings or may be carried by vectors, water or aerial sources which then spread to the whole plant parts subsequently disseminating to tubers through the xylem, which results in quality deterioration of tubers (Essarts et al. 2016).

Climatic conditions in Pakistan are favorable for the occurrence and spread of soft rot and blackleg pathogens although the soil type and potato cultivars are also important determinants in the degree of severity of the diseases. In previous reports, 20–80% incidence of bacterial soft rot was revealed in Azad Jammu and Kashmir regions (Anwar et al. 2013). Similarly, Ali et al. (2012) reported 60–75% incidence of blackleg and potato soft rot from different potato-growing regions of Khyber Pakhtunkhwa which corresponded to 40% disease severity. Bibi et al. (2013) also showed a high prevalence of the soft rot and blackleg pathogenic strains in Khyber Pakhtunkhwa and attributed the disease to 30% losses of the potato crop in the province. Studies conducted by Muhammad et al. (2013) revealed a high prevalence of blackleg and other fungal, bacterial and viral diseases with associated crop losses of potato in different parts of Pakistan. Ali et al. (2013) attributed soft rot and blackleg diseases of potato to huge economic losses as a result of crop damages in fields and storage facilities. Akbar et al. (2015) reported the prevalence of aggressive strains of the soft-rot causal agents in potato, tomato and other vegetables collected from different markets and storage conditions. In a recent study, *D. dianthicola* was reported from the Okara district for the first time which exhibited blackleg and soft-rot symptoms on the potato in field and storage conditions (Sarfraz et al. 2018).

Common scab

Common scab of potato caused by *Streptomyces scabiei, S. europaeiscabiei, S. acidiscabiei, S. turgidiscabiei, S. stelliscabiei* and many other species is another problematic disease of potato crop generally found in soil as well as on plant debris. The species greatly vary in their pathogenic potentials, *Streptomyces scabiei*, however, is considered as the most problematic species because of its capacity to produce thaxtomin A –a plant phytotoxin (Sarwar et al. 2018). The pathogen is a gram-positive filamentous bacterium commonly occurring in soil and causing scabby lesions on potato tuber by producing a toxin, thaxtomin A which deteriorates cortical and epidermal tissues of the tuber (Braun et al. 2017a, b). Disease symptoms become evident on tubers as superficial or deep corky stains which spoil potato tubers after the pathogen attacks host tissues and produces thaxtomin (Leiminger et al. 2013). The production of thaxtomin results in disruption of outer cells of tubers which may result in the formation of extra layers leading to lesion development on the tuber skin (Wanner et al. 2014). Although the disease has no significant impact on the yield and production of potato, tuber quality, however, is severely affected which depends on the environment and field conditions. Rejection of potato due to deteriorated quality caused by scab may cause severe economic losses which are variable in different countries depending on the aggressiveness of the pathogen, susceptibility of potato cultivars, soil conditions and control practices.

The occurrence of common scab in Pakistan is prevalent throughout the country where the potato is cultivated (Anwar et al. 2013; Sarwar et al. 2017). A comprehensive survey carried out by Bhutta (2008) in Northern parts of Pakistan revealed that common scab and bacterial wilt were devastating diseases of potato during 2007. Anwar et al. (2013) showed the prevalence of scab diseases with different incidence rate (20–70%) in potato growing areas of Azad Jammu and Kashmir (AJK). Atiq et al. (2013) asserted that potato scab was a major problem in the country. They reported differential susceptibility of twelve potato lines in Faisalabad where disease incidence ranged between 37.5 and 59.8%. Rafiq and Bukhari (2014) stated that common scab of potato is a leading concern in the country which has drastic effects on the quality and marketability of tubers. Muhammad et al. (2013) evaluated 30 local varieties of potato for yield and resistance response to different bacterial, viral and fungal pathogens. They reported that common scab had a significant impact on quality and yield of potato. During 2015, the high prevalence of common scab pathogen was recorded from different potato fields in Punjab province (Sarwar et al. 2017). Recently, Sarwar et al. (2018) documented *S. turgidiscabiei* and *S. stelliscabiei* as the causal agents of potato scab in different locations of the Punjab province with disease indexes as 63 and 130.5 respectively in addition to *S. scabiei* for which the disease index was recorded as 78.

Control methods

Chemical control

Control methods of the listed bacterial diseases and several other phytopathological problems generally rely on excessive chemicals application which is helpful to some extent in the control of such diseases. Bacterial wilt is generally managed by applying chemicals as fumigants, seed dressing, and sprays. Widely used chemicals for wilt control such as 1,3-dichloropropene, methyl bromide, and the addition of acidic water to soil have been shown to significantly reduce the disease incidence and severity (Nion and Toyota 2015). Applications of phosphorus acid as potassium salt also exhibit some bactericidal properties against wilt bacteria; however, the complete annihilation of the pathogen from soil seems very difficult (Norman et al. 2006). Antibiotics such as streptomycin either alone or in combination with some organic or inorganic compounds show efficient results in field conditions while 5-nitro-8-hydroxyquinoline and hydroxyquinoline are effective against soft rot and blackleg under laboratory conditions (Czajkowski et al. 2011). Nalidixic acid sodium salt linked with zinc compounds has also been recommended as an effective chemical to treat soft rot of potato (Morales-Irigoyen et al. 2018). For control of common scab, pesticides (Captan, Rizolex etc.), 2,4-dichlorophenoxyacetic acid, fluazinam, mancozeb and fludioxonil as seed dressing, spray or soil additive work well under field conditions (Hosny et al. 2014; Thompson et al. 2014; Al-Mughrabi et al. 2016; Santos-Cervantes et al. 2017).

Integrative approaches

Evidently, chemical control of bacterial, fungal and pest incited diseases results in optimal yields and quality improvement, their use in agriculture however also results in environmental problems, disturbance of ecosystem and toxic effects on the human and other organisms (Majeed 2018). Therefore, minimum use of slowly degradable synthetic chemicals for control of phytopathogenic diseases and adoption of integrated disease control strategies such as the use of biocontrol agents, natural compounds, crop rotation and several other cultural techniques may prove an eco-friendly approach towards maintaining the stability of environment (Majeed et al. 2017). Ji et al. (2005) suggested that crop rotation and use of resistance-induced cultivars of potato are ideal strategies to cope with bacterial diseases for minimal use of synthetic chemicals. Crop rotation reduces the chances of survival of soil-borne bacteria because, for longer periods, non-availability of hosts can increase their elimination rate. For the survival of pathogenic bacteria of potato, soil composition and nutritional status play a pivotal role. Analysis of soil for pH, nutrients and moisture content prior to sowing of potato can help farmers to modify crop cultivation outlines. In areas where environmental conditions seem ideal for wilt, soft rot, blackleg and common scab of potato, cultivation of potato should be avoided and alternative crops may be grown in those areas. Evading contamination of healthy tubers from infected ones, nutrient supplement and use of specific fertilizers are regarded as some of the important integrated strategies to minimize adversities caused by bacterial pathogens in field and storage (Czajkowski et al. 2011).

In recent years, major efforts have been directed towards the use of compounds of natural origin and biocontrol agents (BCAs) to deal with plant pathogens since these methods prove as an alternative option to chemical pesticides. In previous studies, different species of *Streptomyces*, *Bacillus,* and *Pseudomonas* while some bacteriophages served as biological antagonists to *R. solanacearum*, the causal agent of bacterial wilt and resulted in significantly lower disease incidence (Maji and Chakrabartty 2014; Nion and Toyota 2015; Álvarez and Biosca 2017). Srawar et al. (2018) identified an antagonistic plant growth promoting bacterium (*Streptomyces* strain A1RT) as a biocontrol agent against the pathogenic *Streptomyce*s sp. They recorded a significant improvement in root and shoot length and tuber weight and reduced disease severity of the challenged plants when the antagonistic strain was applied. In other studies, different strains of *Lactobacillus plantarum*, *Pseudomonas fluorescens* and *Pseudomonas putida* and several antagonistic species of *Streptomyces* had been shown to exhibit antibacterial activity against soft rot, blackleg and common scab pathogens both in field and laboratory conditions (Arseneault et al. 2016; Essarts et al. 2016; Tsuda et al. 2016; Tomihama et al. 2016). Moreover, the use of plant extracts, essential oils and soil amendments with non-toxic organic compounds seems an attractive area for researchers to utilize them against bacterial diseases as an alternative approach to pesticides.

Conclusion

Bacterial wilt, soft rot, blackleg and common scab caused by different pathogenic bacteria are economically important diseases of potato prevalent throughout the world. In Pakistan, these diseases are concurrently prevalent in almost all of the potato growing regions and serve as a matter of significant concern because of their impact on the crop health, tuber quality and yields. Yield losses and crop damages associated with the common bacterial diseases in the country are variable. The diseases cause significant economic losses due to deterioration of potato quality and marketable acceptance. The severity of the diseases is dependent on the environmental conditions, the susceptibility of potato cultivars, soil quality, and agricultural practices. Seeds dressing with chemicals and soil amendments with suitable acidic or alkaline compounds generally reduce disease severity but cannot completely eliminate the pathogens. Moreover, these chemicals also cause environmental pollution and health hazards. Thus, integrated control strategies such as crop rotation, maintenance of soil quality, use of biocontrol agents and compounds of natural origin need wide adoption in potato growing regions to minimize the use of pesticides.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Statement of human and animal rights This article does not contain any studies with human or animal subjects performed by the any of the authors.

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